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LOW-SIGNAL AMPLIFYING VALVES FOR USE AT U.H.F.

Report No. G-074

(1959/8)

THE BRITISH BROADCASTING CORPORATION

ENGINEERING DIVISION

RESEARCH DEPARTMENT

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1. INTRODUCTION

The possible use of Bands IV and V (470-585 Mc/s and 610-960 Mc/s, respectively) for broadcast purposes has led to interest in receivers operating at these frequencies with a good performance in respect of noise and selectivity. In superheterodyne receivers the mixer stage is an important source of noise. At lower frequencies the selectivity of a receiver and the signal-to-noise ratio of its output can be improved easily by preceding the mixer stage by a stage of r.f. amplification. At u.h.f. amplification is difficult owing to transit-time effects, and the noise introduced by an amplifier stage becomes comparable with that introduced by the mixer stage. Careful design of the valve and its associated components is therefore necessary to obtain any advantage over the present commonly-used arrangement of a crystal mixer as the first stage.

The object of this report is to review some of the types of valve that are suitable for use in u.h.f. amplifying stages in receivers, and to describe units which have been constructed to test the performance of two of these valves at a frequency of about 655 Mc/s.

2. TYPES OF VALVE AVAILABLE

In a u.h.f. amplifier stage it is usual to employ a triode valve arranged for connection as a grounded-grid amplifier. A triode has the advantage of low partition noise compared with a pentode, whilst the grounded-grid connection avoids the necessity for neutralization. The input impedance is low and largely resistive so that matching of the input over a wide band to a feeder of about 70 ohms is relatively easy. U.H.F. triodes are usually constructed for use as grounded-grid amplifiers by bringing out several connections from the grid electrode, thus reducing series inductance. This technique is brought to its logical conclusion in the disc-seal triode where the grid is connected to a conducting disc which projects out through the glass envelope of the valve.

Among the valves with conventional pin bases manufactured in the United Kingdom are the A2521 made by G.E.C. and the 6AM4 made by Brimar. Valves using the disc-seal construction are the TD03-5 (CV354) made by Mullard, and its equivalent the DET23 made by G.E.C. The Mullard EC56 is also of the disc-seal type but has the "lighthouse" type of construction, its heater and d.c. cathode connections being brought out on a conventional pin base. It is a more expensive type of valve capable of operation up to 4000 Mc/s.

3. CONSTRUCTION OF U.H.F. AMPLIFIERS

Two amplifiers were constructed to investigate two types of valve; they were designed for unbalanced input and output connections (with impedances of 70 ohms) in order to facilitate measurements of stage gain and other parameters.

3.1. Amplifier Using the A2521 Valve

Fig. 1 shows the electrical circuit of the amplifier using an A2521 valve and Figs. 2 and 3 show the mechanical layout of the input and output circuits

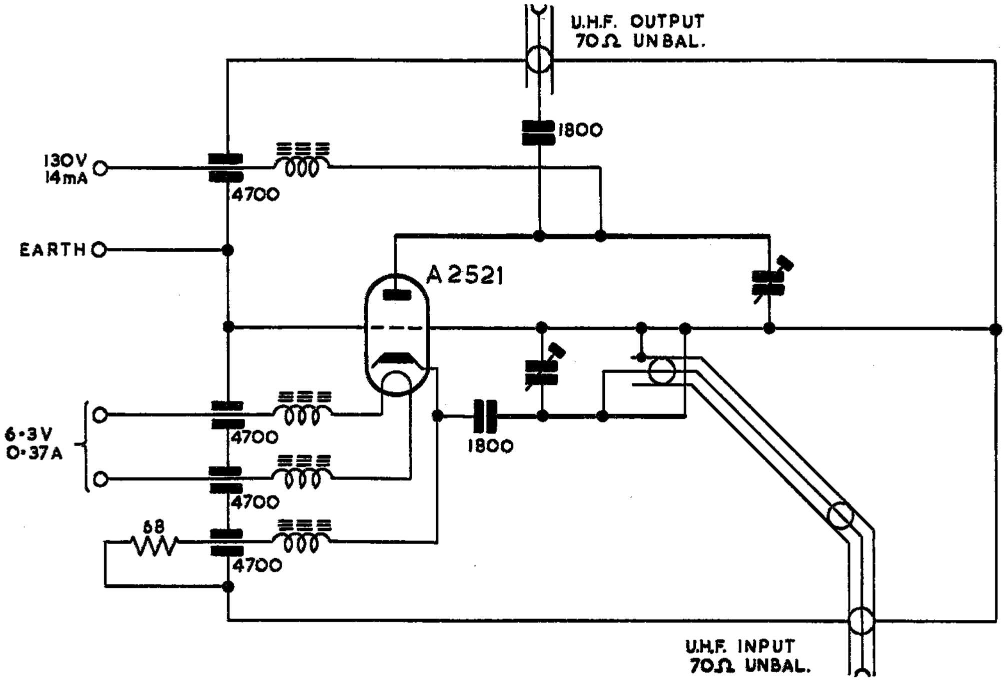

Fig. 1 - Electrical circuit of the A2521 amplifier

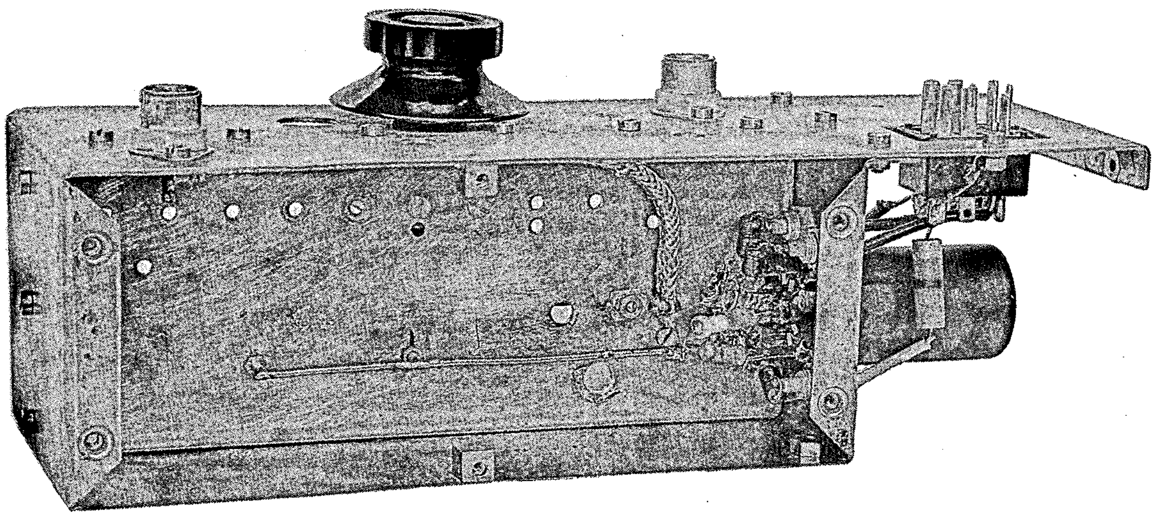

Fig. 2 - A2521 amplifier — input circuit

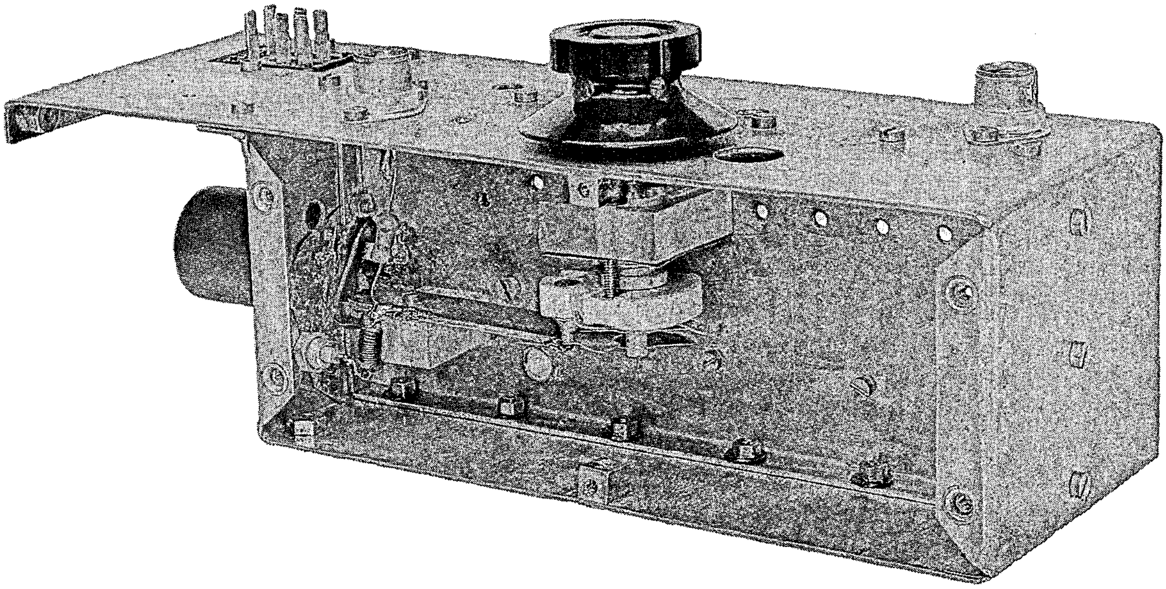

Fig. 3 - A2521 amplifier — output circuit

respectively, with cover plates removed. The valve is mounted in a modified type of standard paxolin B9A valve holder which is shown in Fig. 4. Early tests were made using a standard P.T.F.E. valve holder, but it was found that the inductance in the electrical path between the chassis of the amplifier and the grid electrode was sufficient to cause considerable positive feedback. The modified valve holder gave a shorter path for grid currents and gave the connections a much greater cross-sectional area than in a normal valve holder. (An amplifier has been constructed by E.M.I. Electronics using an A2521 valve, in which a different mechanical layout is used. In the description of its performance[1] positive feedback due to grid lead inductance is not mentioned and may well be unimportant with the mechanical layout employed.)

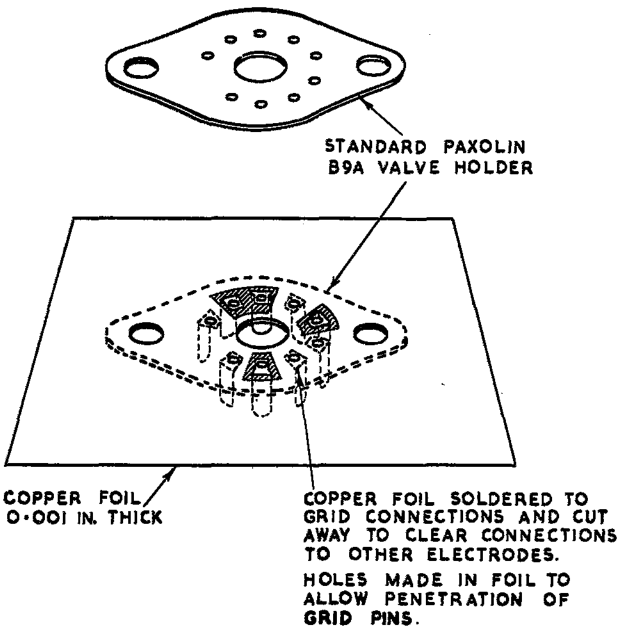

Fig. 4 - Modified B9A paxolin valve holder

As may be seen from Figs. 2 and 3, the input and output circuits are in separate screened compartments, the dividing wall of which is connected to the grid of the valve. Power supplies are fed into the amplifier by ceramic feed-through capacitors and r.f. chokes. The u.h.f. input is fed to the cathode through a

coaxial socket, matching network and d.c. blocking capacitor. Bias voltage is developed across a 68-ohm resistor in the d.c. connection to the cathode. The anode tuned circuit is a strip line electrically half a wavelength long formed by a brass strip approximately 2 in. (5 cm) long. It is attached to the anode pin at one end and to a tuning capacitor at the other end. H.T. power is fed to the strip line at the point where there is an electrical node at mid-band frequency. The u.h.f. output is taken from a coaxial socket, the centre connection of which is coupled to the strip line via a d.c. blocking capacitor. The position of the coupling point is adjusted to provide the required output impedance or bandwidth at a given frequency.

The results obtained in measurements made on the amplifier are given in Section 4.

3.2. Amplifier Using the TD03-5 Valve

An electrical circuit diagram of the amplifier designed to use a TD03-5 valve is shown in Fig. 5. Photographs of the input and output sections of the amplifier with their cover plates removed are shown in Figs. 6 and 7 respectively. The input and output circuits are in separate compartments formed by the H-shaped chassis and the cover plates. The valve is mounted through a hole in the part of the chassis which forms the dividing wall between the input and output circuits, and the grid is connected to the chassis by a circular spring clip.

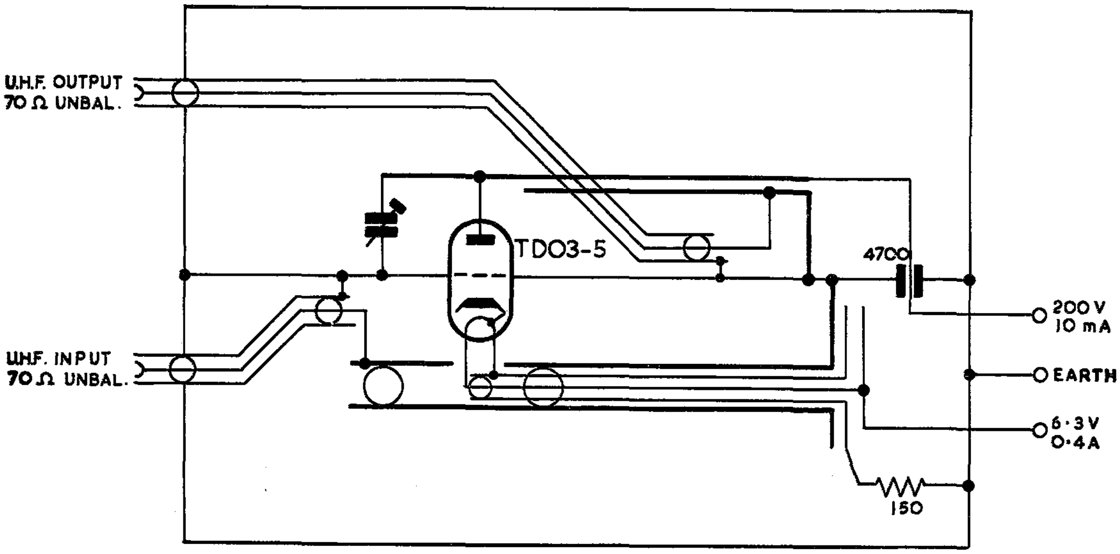

Fig. 5 - Electrical circuit of the TD03-5 amplifier

The u.h.f. input power is fed to the cathode by a cylindrical strip-line matching network. The heater power and cathode bias potential are fed coaxially inside the cylindrical strip line and are decoupled to the chassis in "mica sandwich" capacitors at the short-circuited end of the strip line. Bias is derived from the voltage developed across a 150-ohm resistor in the d.c. connection to the cathode.

The anode connecting ring of the valve is firmly clamped to a strip of brass approximately 4 in. × 1 in. × $\frac{1}{8}$ in. (10 cm × 2·5 cm × 0·3 cm). This forms part of the anode line and is electrically a quarter wavelength long; it is short-circuited

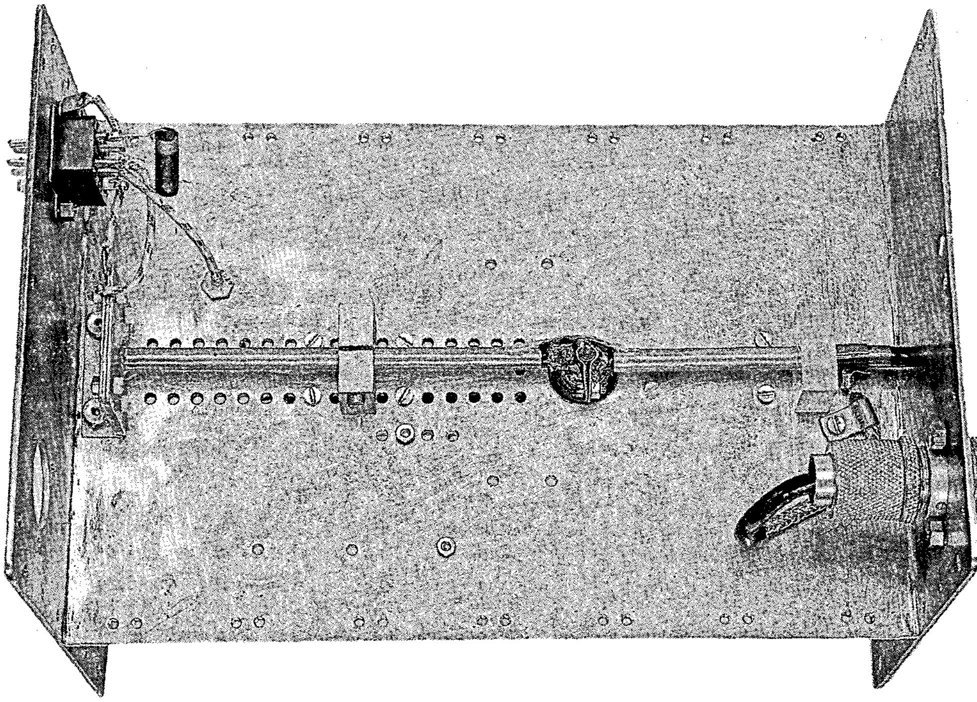

Fig. 6 - TD03-5 amplifier — input circuit

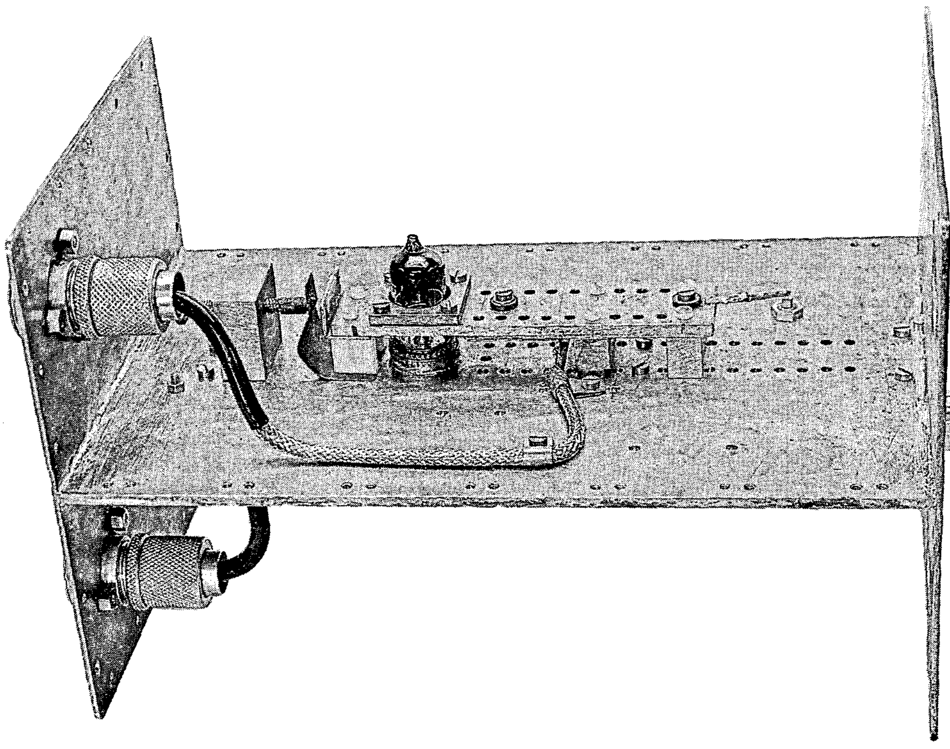

Fig. 7 - TD03-5 amplifier — output circuit

to the chassis at one end and has the anode of the valve and a tuning capacitor at the other end. The valve manufacturer's specification states that the mass of metal in close thermal contact with the anode disc should not be less than 2 oz (60 gm) of brass or its equivalent. The complete anode line is made in the form of a "mica sandwich" such that the metal on either side of the mica is practically at the same u.h.f. potential but at different d.c. potentials. The top part of the sandwich is at h.t. potential and the bottom part is at zero potential and is connected to the chassis. The u.h.f. output from the amplifier is taken from a tapping point on the "earthy" side of the anode line to provide the required output impedance or bandwidth at a given frequency.

The results of measurements made on the amplifier are given in Section 4.

4. MEASURED PERFORMANCE OF THE AMPLIFIERS

4.1. Tuning Arrangement

Both amplifiers were constructed so that their mid-frequency could be adjusted at least over the range 650–660 Mc/s. The continuous tuning ranges of the A2521 and TD03-5 amplifiers were in fact about 610–700 Mc/s and 540–670 Mc/s respectively. In each case, however, the design was such that a much coarser adjustment of mid-frequency was available by simple mechanical alterations to the anode and cathode lines.

4.2. Input and Output Impedance

A General Radio admittance meter was used to make measurements of the input and output admittances. The amplifiers were tuned to about 655 Mc/s, and a 70-ohm resistive load was connected either to the input or to the output socket (whichever was not under test). The normalized impedances referred to the rear of the input and output sockets are shown in Figs. 8 and 9 respectively.

4.3. Gain and Bandwidth

The gain and bandwidth were measured using as a standard the piston attenuator on a signal generator. The amplifiers were tuned to the frequencies used in the previous measurements and the gain was measured between equal source and load impedances of 70 ohms. The results are shown in Fig. 10. It should be noted that the bandwidth is largely a consequence of the particular matching adjustments; no attempt was made to achieve a wide bandwidth.

4.4. Noise Factor

The noise factor of each amplifier was deduced by using a 50-ohm coaxial diode noise generator, first to measure the noise factor of a u.h.f. converter feeding into a v.h.f. receiver and then to measure the noise factor of this combination preceded by the amplifier. The input impedance of the u.h.f. converter was adjusted to present a 70-ohm resistive impedance to the output of the amplifier and noise generator. The results were as follows.

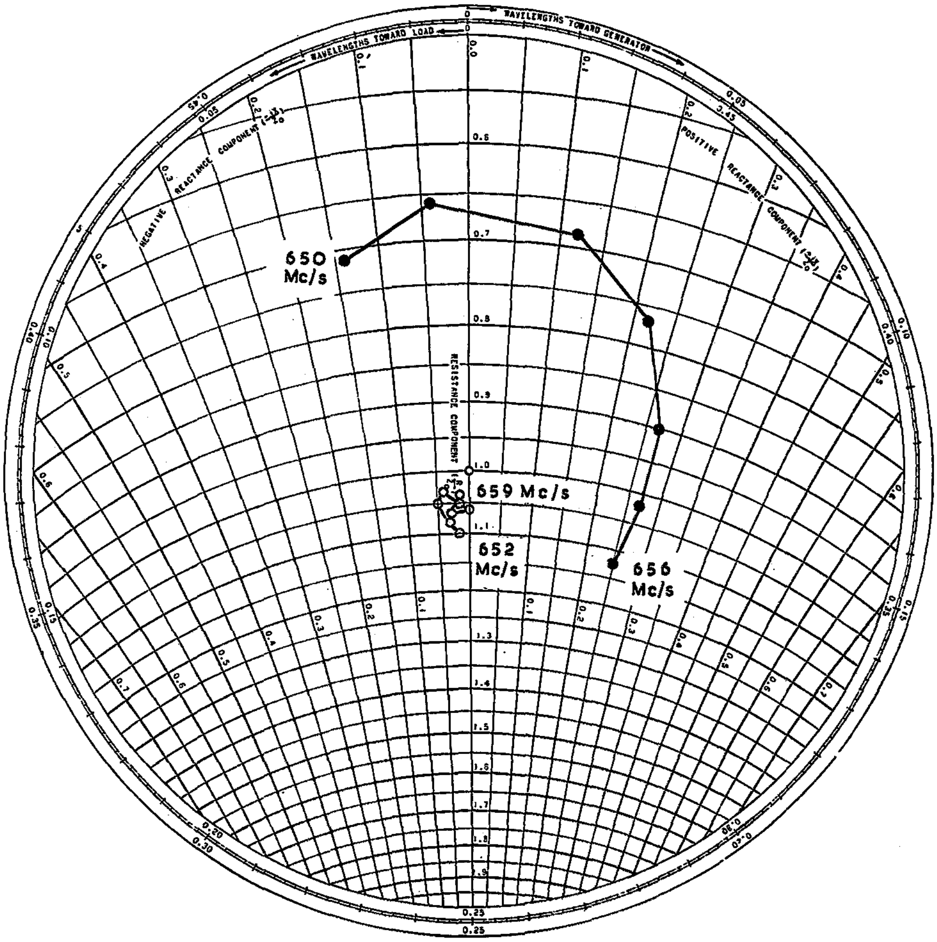

Fig. 8 - Amplifier input impedance normalized to 70 ohms
—o—o— A2521 amplifier
—●—●— TD03-5 amplifier

	A2521 Amplifier	TD03-5 Amplifier
Noise factor of u.h.f. converter feeding into v.h.f. receiver	13·1 dB	16·1 dB
Noise factor of amplifier feeding into u.h.f. converter followed by v.h.f. receiver	10·9 dB	11·5 dB
Mid-band gain of amplifier	11·6 dB	10·5 dB
Deduced noise factor of amplifier	10·4 dB	10·2 dB

(Different u.h.f. converters were used for each amplifier)

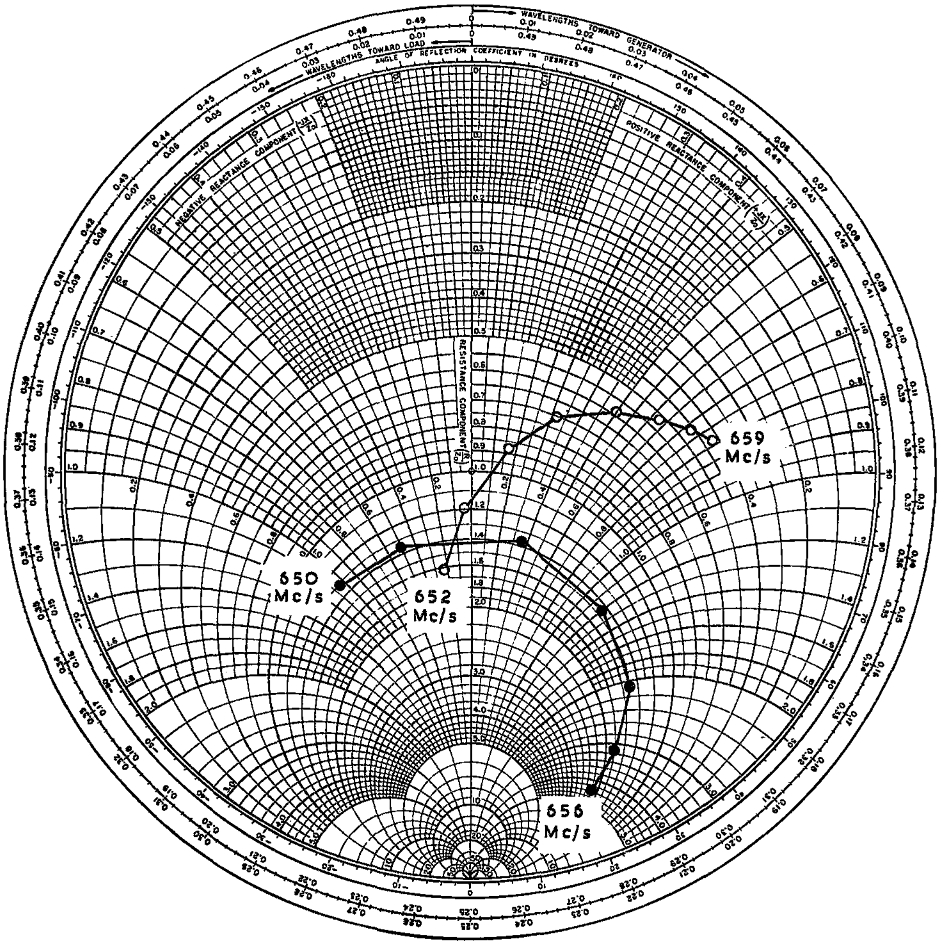

Fig. 9 - Amplifier output impedance normalized to 70 ohms

—o——o— **A2521 amplifier**

—●——●— **TD03-5 amplifier**

4.5. Effect of Change of Valve

The A2521 valve was replaced by the only available spare A2521. Before any adjustments were made to the circuit the following changes were noted:

Change of mid-band frequency	+3·5 Mc/s
Change of mid-band gain	0 dB

The valve in the TD03-5 amplifier was replaced in turn by two other TD03-5s and also by a DET23. Before any adjustments were made to the circuit the following changes were noted:

Change of mid-band frequency	TD03-5 (i)	−5 Mc/s
Change of mid-band gain	TD03-5 (i)	+0·7 dB
	TD03-5 (ii)	+0·2 dB
	DET23	0 dB

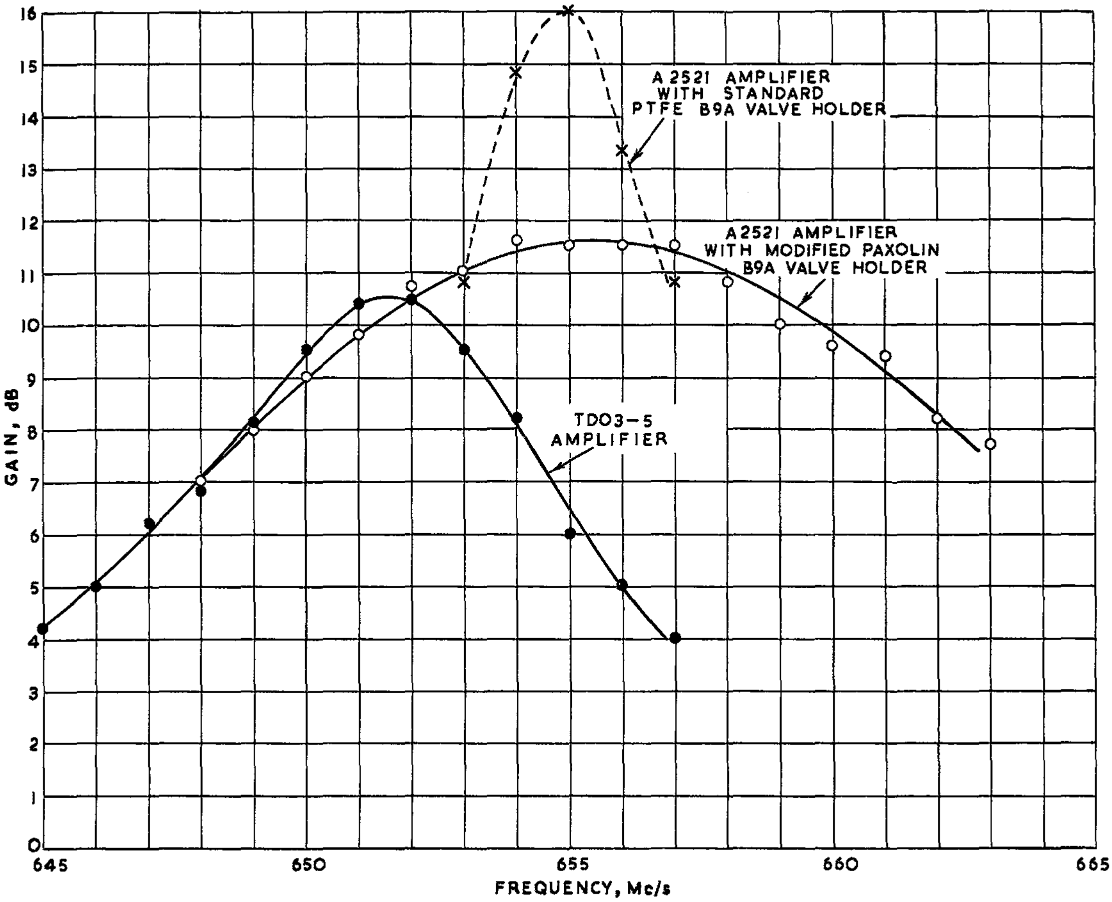

Fig. 10 - Amplifier gain

4.6. Valve Life

The TDO3-5 amplifier was in almost daily use for about five months without any change of valve. There was no detectable deterioration of performance over this period.

5. DISCUSSION OF RESULTS

The amplifiers were constructed primarily to check the performance of the valves at one frequency. For the purposes of gain measurement, adjustments were made for a mid-band output impedance of approximately 70 ohms. At this stage no attention was given to the resulting bandwidth. It was known from later experiments, however, that the bandwidth of the TDO3-5 amplifier could be increased considerably by using different settings of the output matching network. In fact the bandwidth could be almost doubled with no noticeable decrease in mid-band gain. It is theoretically possible to increase the bandwidth of both amplifiers by employing double-tuned anode circuits.

In Fig. 10 the gain of the A2521 amplifier using a standard P.T.F.E. B9A valve holder is shown for comparison. The apparent Q-factor of the unloaded anode

tuned-circuit in this case is about 400. This is a high value for this type of circuit and suggests that positive feedback is present. This is confirmed by the fact that the gain reaches a higher value than that obtained in the final amplifier with an improved valve holder. It may be shown that inductance between the grid of the valve and earth in a grounded-grid amplifier gives rise to positive feedback. This was checked in the A2521 amplifier by partly withdrawing the valve from its holder, thus lengthening the path between grid and earth, and also by removing one of the grid connections on the valve holder, thus decreasing the cross-sectional area of the grid connections. In each case the apparent Q-factor rose to over 600. A measurement of the backwards attenuation of the amplifier (i.e. the attenuation from output to input) gives the amplitude of the feedback ratio, but gives no information concerning the phase. Since we have reason to believe that it is in the positive sense in the A2521 amplifier, the following measurements of backwards attenuation are of interest:

A2521 Amplifier	Backwards Attenuation (dB)
Using modified paxolin valve holder	35
Using standard P.T.F.E. valve holder	24
Using standard P.T.F.E. valve holder with valve partly withdrawn	18
Using standard P.T.F.E. valve holder with one grid connection removed	7·5

It is evident from these figures that considerable attention should be paid to the way in which connections are made to the valve pins. An attempt was made to test the 6AM4 valve in the chassis which was constructed for the A2521, but oscillation could not be prevented when the amplifier was tuned to frequencies between 600 Mc/s and 700 Mc/s even though the modified paxolin valve holder was used.

When the noise factor of the amplifiers was measured no attempt at improvement was made by changing the input tap on the matching circuit. It was thought that the tedious work involved would not be justified by the possible small improvement in noise factor.

6. CONCLUSIONS

It has been shown that a single-stage amplifier incorporating the A2521, TD03-5 or DET23 valves will give a gain of about 11 dB with a bandwidth suitable for television channels at a frequency of about 655 Mc/s. The amplifier noise factor at this frequency is about 10 dB. These figures correspond quite well with those given by the manufacturers (see Appendix).

A description of the design and performance of the A2521 valve has been published by the manufacturer[2] since the completion of the experimental work described in this report.

A detailed account of the design of an amplifier using an EC56 valve has been described elsewhere.[3] The measured gain at 600 Mc/s was 16 dB with a bandwidth of 7 Mc/s.

It has been shown that the mechanical layout of a u.h.f. amplifier is of great importance if positive feedback is to be avoided, and that special attention should be given to the connections to the grid of the valve. The disc-seal valve reduced the problem of positive feedback by lending itself to a design of amplifier where the input and output circuits are virtually isolated. The disadvantage of the disc-seal valve is its need for special mounting brackets and clips. The TD03-5 has the additional disadvantage of requiring a large bulk of metal in thermal contact with its anode.

7. REFERENCES

1. Gant, H.N., "Television Reception on Band V", Wireless World, Vol. 64, No. 5, p. 244, May 1958.

2. Williams, A.D. and Gore, D.C., "Design and Performance of a New Low-Noise Triode for use up to 1000 Mc/s", Proc. I.E.E., Vol. 106, Part B, No. 25, p. 35, Jan. 1959.

3. Rieck, H., "The Basis of a Low-Noise Pre-Amplifier for λ = 70-40 cm", Nachrichtentechnik, Vol. 8, No. 7, p. 306, July 1958.

APPENDIX

Typical Operating Conditions, Performance, and Valve Parameters Quoted by Manufacturers

	A2521	TD03-5, DET23	6AM4	EC56
V_a	130 V	250 V	200 V	220 V
I_a	16 mA	10 mA	10 mA	30 mA
V_f	6·3 V	6·3 V	6·3 V	6·3 V
I_f	0·37 A	0·4 A	0·225 A	0·65 A
V_g	−1 V	−2 V	−1 V	−4 V
μ	60	70	85	43
g_m	15 mA/V	6·5 mA/V	9·8 mA/V	19 mA/V
Electrode Capacity				
$C_{k+h,\,g}$	4·0 pF	2·0 pF	4·6 pF	3·3 pF
$C_{a,\,g}$	1·8 pF	1·0 pF	2·4 pF	1·6 pF
$C_{k+h,\,a}$	0·07 pF	0·01 pF	0·16 pF	0·04 pF
Power Gain and Bandwidth	Gain at 900 Mc/s, 10 dB; bandwidth for 3 dB fall in response, 50 Mc/s			Gain at 4000 Mc/s, 12 dB; bandwidth for 0·1 dB fall in response, 50 Mc/s
Noise Factor	8·4 dB at 500 Mc/s to 11·5 dB at 900 Mc/s	9·5 dB at 1000 Mc/s with 15 dB power gain		

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